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### Ultrasonic Transducer

The present invention relates to an ultrasonic transducer for use as a transmitter and receiver in pulse-echo applications, in which air is the transmission medium for the sound wave.

A particular field of application for the ultrasonic transducer as a sensor is the motor vehicle sector. In this field there is a need for transducers for detecting objects in the interior of the vehicle, for example to control the triggering of an airbag during an accident.

There are already numerous ultrasonic transducers for such applications on the market. The bending vibration of a membrane has proven to be an especially effective mode of transducer vibration. In order to generate vibration, a round piezoceramic disk is glued in the center on the rear side of a membrane. By applying an electric field, the ceramic is excited to radial vibrations. Stiff adhesive bonding to the membrane yields a bending vibration of the

whole system. In addition, a piece of foamed material for dampening the vibration is provided on the rear side of membrane.

The parameters of the ultrasonic vibration are determined by the elastic and other mechanical properties of the overall system. The elastic properties of the employed materials and the geometric dimensions of the employed components influence the resonance frequency, the aperture angle of the sound lobe, the quality  $Q$  of the vibration and the sensitivity of the sensor.

A multiplicity of influential factors that influence each other therefore determines the physical properties of a transducer.

In the above application for controlling airbag triggering during an accident, transducer properties are required that have never been fulfilled in this manner by any of the known transducers. The transducers available on the market all have one or more of the following drawbacks, thus for example too little sensitivity, too small a sound emission aperture angle, no closed form of encasement, insufficient resistance to outside mechanical influences, too high a

mechanical quality Q. Furthermore, they are often too complicated in operation and therefore too difficult to produce.

Therefore, the object of the present invention is to provide an ultrasonic transducer and a process for its fabrication, which has great sensitivity while having a low quality Q as possible and having a large aperture angle. Moreover, it should be possible to execute the transducer in a robust, sturdy encasement and produce it in large piece numbers.

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~~This object is solved with the ultrasonic transducer and the process according to the features of claims 1 and 15. Advantageous embodiments of the ultrasonic transducer and the process for its fabrication are the subject matter of the subclaims.~~

A key element of the present invention is that an ultrasonic transducer is proposed in which a membrane is disposed in a holding means and a piezoelectric disk is placed on a main surface of the rear side of the membrane. The diameter of the piezoelectric disk is between 60% and 85% of the diameter of the membrane. A first substance is foamed onto the main surface of the rear side of the membrane. Foaming on this substance make it possible to obtain particularly advantageous transducer properties with regard to sensitivity and mechanical quality Q. With the foamed on substance, the described relationship of the diameter of the piezoceramic to the diameter of the membrane yields a large sound emission aperture angle.

The holding means of the ultrasonic transducer which simultaneously forms the encasement can be inexpensively fabricated with the membrane in one piece of one material, for example aluminium or an aluminium alloy (e.g. AlCuMgPb). A holding means that forms with the membrane a pot-shaped structure permits providing a robust transducer sufficiently resistant to outside mechanical influences. The transducer can be fabricated with a simple process, for example an extrusion process, and fulfills therefore the

requirements of inexpensive fabrication in high piece numbers.

In particular, the thickness and the diameter of the ceramic, the thickness and the diameter of the membrane and the overall height of the aluminium encasement essentially influence the properties of the transducer. Thus the center frequency  $f$  of the ultrasonic transducer is proportional to the ratio of the square membrane diameter  $D_M^2$  to the membrane thickness  $d_m$ . On the other hand, the ceramic thickness  $d_k$  is proportional to the center frequency  $f$ . The relationship depends on the respective design. Moreover, the sensitivity and the related mechanical quality  $Q$  of the vibration can be influenced by the material on the rear side of the ceramic (first substance).

A special ultrasonic transducer for the application of object detection in the interior of a motor vehicle, for example for controlling the triggering of airbags during an accident, operates at a center frequency of 70 kHz. At this frequency, the aperture angle of the 6dB sound lobe should be as large as possible. Such a system requires that all

the essential objects with their different surface structure and materials reflect a detectable echo signal in the direction of the transducer. The sensitivity of the transducer has to, therefore, be as great as possible.

An element of the present invention is that a transducer having a membrane diameter of  $8.85 \pm 0.02$  mm, membrane thickness of  $0.83 \pm 0.02$  mm and a ceramic thickness of  $0.26 \pm 0.01$  mm has proven especially advantageous for this application.

Furthermore, a cylindrical holding means having a wall thickness of at least 2.85mm and a height of, for example, 6.83 mm is employed with such a transducer.

greater height of the holding means is, of course, also possible. <sup>A smaller or</sup>

The developed sensor fits in an existing occupation detection system in a motor vehicle system without any further changes to the triggering electronics.

The first substance foamed on the rear side of the membrane is preferably made of an open-cell, soft material, for example polyurethane foam or silicon foam.

Especially advantageous transducer properties are obtained with polyurethane foam having a strain hardness (DIN 53577) of < 9kPa and an acoustical loss factor (DIN 53426) of < 1.0.

In a particular preferred embodiment, a piezoceramic having a relative dielectric constant of > 2500, a radial electromechanic coupling factor of > 0.5 and a mechanical quality Q of < 300 is used as the piezoelectric disk.

In fabricating the invented ultrasonic transducer, first a pot-shaped holding means of aluminium or an aluminium alloy, the bottom of which forms the membrane, is made by means of an extrusion process. A piezoelectric disk is glued onto the rear side of the membrane in order to produce a mechanical and an electric contact to the membrane. One end of a thin wire is soldered onto the piezoelectric disk. Finally, a first substance is foamed onto the rear side of the

membrane in the pot-shaped holding means in such a manner that the membrane and the piezoelectric disk are completely covered by the substance.

The invented ultrasonic transducer is, of course, also excellently suited for other air-ultrasonic applications with similar requirements of the essential transducer properties, for example, for distance measurements or position detection systems. Due to the wide sound lobe, the sensor is particularly suited for areal surveillance.

The present invention is made more apparent in the following using a preferred embodiment and the accompanying drawings, in which

Fig. 1 shows a cross section of an example of an invented transducer,

Fig. 2 shows a rear view of the transducer of fig. 1 without the first substance (4) and the second substance (5),

Fig. 3 shows a rear view of the transducer of fig. 1 completely, and

Fig. 4 shows a front view of the transducer of fig. 1.

A preferred embodiment is now described with reference to figs. 1 and 2.

Fig. 1 shows a cross section of a preferred embodiment of the transducer. The transducer comprises a cylindrical aluminium encasement (1). The bottom of the encasement forms an aluminium membrane (2). The aluminium encasement of the transducer is fabricated as a turned part. A piezoceramic disk (3), for example made of a PZT-5H ceramic, is concentrically glued into the aluminium pot (on the rear side of the membrane (2)) using a thin liquid adhesive with pressure. One electrode of the ceramic, which is glued on the membrane surface, has electric contact via the membrane to the aluminium encasement (1). Mass-contacting is ensured by a copper pin (6) driven into the aluminium encasement. If producing large piece numbers, another process can be selected for mass-contacting. The copper pin is connected to a thin wire (8) with a cable (10) that connects the transducer to the triggering electronics. The other electrode of the ceramic (3) is connected to another thin wire (9) via a soldering point (7) at the edge of the ceramic. Placing the soldering point (7) at the edge of the ceramic minimizes the influence of vibration properties of the system. The wire (9) between the ceramic electrode and cable (10) has to be very light in order to avoid other influencing factors on the vibration properties of the system.

Fig. 2 shows a rear view of the sensor with the aluminium encasement (1), aluminium membrane (2), glued on ceramic disk (3), soldering point (7) and mass-contacting (6).

The selected membrane diameter yields the desired aperture angle (here:  $>45^\circ$  with a lateral 3dB drop in sound pressure;  $>55^\circ$  with a lateral 6dB drop in sound pressure) and is tuned to the overall vibration system.

effectively generate the bending vibration. In the exemplary system, the total height of the encasement, including the thickness and the diameter of the ceramic disk were optimized with regard to the vibration behavior of the system. The thickness of the ceramic has less influence on the vibration behavior than the diameter.

In this example, the components of the ultrasonic transducer (sensor) have the following dimensions:

Thickness of the wall of the encasement $d_G$ :	2.85 mm
Height of the wall of the encasement $h_G$ :	6.83 mm
Diameter of the encasement $D_G$ :	14.55 mm
Diameter of the membrane $D_M$ :	8.85 mm
Thickness of the membrane $d_M$ :	0.83 mm
Diameter of the ceramic disk $D_K$ :	6.75 mm
Thickness of the ceramic thickness $d_K$ :	0.26 mm

All the geometric dimensions of the components involved must be adhered to in order to obtain all aspects of an optimized system for the mentioned application.

An essential parameter of the sensor is the mechanical quality  $Q$ . The first substance (4) foamed onto the rear side determines the dampening of the membrane vibration. The thickness of the wall of the pot may also play a role. The elastic properties of the first substance (4) influence the resonance behavior only to a small degree and permit, by using materials with different dampening, setting the mechanical quality  $Q$  of the transducer.



An additional, second substance (5) applied onto the first substance (4) on the rear side has the purpose to prevent propagation of a sound wave in the direction opposite to the direction of the radiating membrane and is attuned in its influence on the resonance behavior of the whole system. The material of the second substance (5) is a polyurethane and, moreover, fulfills the object of securing the transition between the very light wire that contacts the electrodes and the heavier connection cable.

Fig. 1 shows the degree that the first and second substances (4,5) cover the membrane respectively fill the aluminium encasement. In the embodiment, the distance of the top edge of the second substance (5) to the top edge of the encasement wall (1) is 1.17mm. Finally, figs. 3 and 4 show another rear view and a front view of the entire ultrasonic transducer.